

# RECLAMATION OF SALINE-SODIC SOILS ADJACENT TO THE HEATHCOTE RIVER, CHRISTCHURCH

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## ABSTRACT

Stewart, D.P.C. (1992). Reclamation of saline-sodic soils adjacent to the Heathcote River, Christchurch. *New Zealand Natural Sciences* 19: 45-52.

The Heathcote River cut has shortened the river's course and increased salt water penetration upstream. Soil samples and lysimeters were taken along opposite banks of the Heathcote River in Christchurch. One bank had previously been irrigated for two months with approximately 720 mm water while the other had not. Soil from the unirrigated bank contained 0.19% soluble salts, 749 ppm water soluble chloride, 22.8% exchangeable sodium and 1.85 ppm hot  $\text{CaCl}_2$  extractable boron. Irrigation increased soil pH and reduced soluble salts and water soluble chloride content. The saturated hydraulic conductivity ( $K_{\text{sat}}$ ) of the lysimeters declined rapidly when leached with de-ionised water. Addition of 10 tonne.  $\text{ha}^{-1}$  gypsum increased and maintained both the electrical conductivity of the leachate, and  $K_{\text{sat}}$  of lysimeters that were still permeable. Subsequently, after drying and rewetting all cores  $K_{\text{sat}}$  increased. Water soluble chloride and soluble salts were more rapidly leached than exchangeable sodium and hot  $\text{CaCl}_2$  extractable boron. The irrigation programme in conjunction with gypsum addition was effective except for leaching hot  $\text{CaCl}_2$  extractable boron. Boron adsorption could be reduced by acidifying the soil to facilitate leaching when used in conjunction with irrigation. Care needs to be taken to avoid damaging the surface soil structure.

KEYWORDS: Saline sodic soils - Heathcote River - reclamation - leaching.

## INTRODUCTION

A cut was put in the Heathcote River, Christchurch, as a flood control measure in 1986, effectively shortening its course by 2.8 km (Fig. 1). As the gradient of the river bed is very low, this allowed salt water to penetrate much further upstream than had previously been the case. As a result, salt concentrations have increased in the adjacent soils and parts of the river bank have collapsed. Many willows (*Salix* sp.) and other species along the river bank have died. Salt water has also penetrated laterally from the river in some areas, causing toxicity problems in private gardens. The Christchurch City Council is concerned about the problem, and began a riverbank irrigation programme early in 1991 to try and reduce salt accumulation. They have established that salt concentrations increase with depth to maximum

concentrations of approximately 0.2-0.5% soluble salts and 8-26% base saturation sodium at between 0.9 and 1.2 m (Christchurch City Council 1991a). They also recorded lateral movement of salt of up to 23 m from the river. The Council has undertaken some bank works to prevent further bank slumping, and has signposted parts of the river bank as "Environmentally Sensitive" prohibiting vehicular parking. Currently the Council is considering building a structure to reduce upstream tidal flow through the cut (Heathcote River Task Force Tidal Control Study Team 1991).

Little research investigating the reclamation of saline and sodic soils has been done in New Zealand, even though New Zealand has 35 000 ha of saline soils (Gibbs 1980). Research has mainly been confined to stopbanking and draining these soils, and allowing rainfall to slowly reduce soil salt

concentrations (Doak 1931, Dixon & Harris 1938, Glanville 1943, 1947). New Zealand acid sulphate soils have been reclaimed using a combination of drainage and lime (Metson *et al.* 1977), however the main problem with these soils is their low acidity rather than their soluble salt content.

Much research on the reclamation of saline and sodic soils has been done overseas (Sharma & Khosla 1984, Shainberg 1985, Hoffman 1986, Shainberg *et al.* 1989). Soils of this type occupy almost 33% of potentially arable land in the world (Gupta & Abrol 1990). High concentrations of salts in the soil increase the effective moisture stress for plants and can be toxic (United States Salinity Laboratory Staff 1954). These salts are relatively soluble and leaching is generally used to reclaim saline-sodic soils (Sharma & Khosla 1984, Hoffman 1986, Shainberg *et al.* 1989, Gupta & Abrol 1990). The importance of maintaining a high electrical conductivity in the soil solution to avoid colloidal dispersion, until the exchangeable sodium percentage is reduced, is widely recognised (Shainberg 1985, Shainberg *et al.* 1989, Gupta & Abrol 1990). This is often achieved by adding gypsum (calcium sulphate) which increases the electrical conductivity of the soil solution and replaces calcium for sodium on the cation exchange sites. This reduces soil swelling and dispersion and increases porosity, structural stability and improves hydraulic properties (Shainberg *et al.* 1989). Increases in infiltration rates of sodic soils by 540% have been recorded after applying 10 tonne.ha<sup>-1</sup> gypsum (McIntyre *et al.* 1982), and between 300 and 1600% with 5 tonne.ha<sup>-1</sup> (Shainberg 1985). Due to the high concentration of boron in sea water (Keren & Bingham 1985), and the sensitivity of plants to boron concentration (Aubert & Pinta 1977), soil inundated with sea water can readily inhibit plant growth. Boron is more slowly leached from saline soils than other salts, as most soil boron is specifically adsorbed and is not in solution from where it can be readily leached (Keren & Bingham 1985).

The aim of this work was to quantify the riverbank soil conditions of the Heathcote River, to evaluate the effectiveness of the irrigation programme in reducing the soluble salt, chloride and boron concentrations, and to determine if using gypsum in conjunction with irrigation is more effective than irrigation alone.

## MATERIALS AND METHODS

### SAMPLING

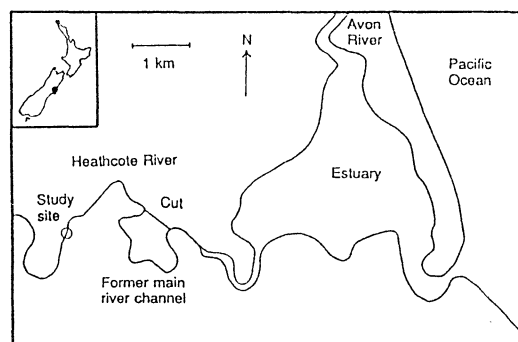


Figure 1. The Heathcote River and cut, and the study site.

Soil samples were taken on the banks of the Heathcote River, Christchurch, upstream from the Opawa Road bridge for approximately 100 m (Fig. 1). Ten undisturbed soil monolith lysimeters were taken (18 cm diameter by 22.5 cm long). Of these, five were taken from the east bank which had previously been irrigated by the council each night for two months (12 mm/night giving a total of 720 mm) during the summer of 1990/91 (cores 1-5). Another five were taken from the west bank which had received no irrigation (cores 6-10). In comparison with this irrigation, the long term mean annual precipitation for Christchurch is 666 mm, of which 97 mm would generally fall during the irrigation period (January/February). The lysimeter cores were taken at intervals along the bank approximately opposite each other. Lysimeter cores were collected by removing the soil from around an approximately 21 cm diameter soil monolith. Lysimeter casings of 19 cm diameter P.V.C. pipe with an internal cutting ring were then pushed gently down over the exposed soil monolith. Liquified petroleum jelly was injected into the 0.5 cm gap between the soil and casing and allowed to solidify before the core was detached from the surrounding soil. This provided support for the core during transport and prevents edge flow during subsequent leaching experiments (Cameron *et al.* 1990).

Additional samples were taken immediately adjacent to each soil core. These included duplicate bulk density cores from 0-10 and 10-20 cm

collected using a 4.5 cm diameter corer. Bulk density is the field soil density *ie.* including pores (McLaren & Cameron 1990). Samples were oven dried at 105°C. Bulk soil samples for chemical analysis were also taken at 0-10 and 10-20 cm increments.

Unfortunately sampling was interrupted by rain. Cores 1-5 were taken on 28 March 1991. Cores 8-10 and bulk samples 1-5 and 8-10 were taken seven days later, after 23 mm of rain. Cores 6 and 7 and their bulk samples were taken after a further 5 days and 38 mm of rain.

#### LEACHING OF CORES

An acetone/cellulose acetate paste was applied over a cloth to the bottom of each core and allowed to dry. Once dry the paste was peeled off, removing the smeared lower surface of each core. This ensured the hydraulic conductivity of cores was representative of the field soil (Cameron *et al.* 1990). Depressions in the base of the core were filled with acid washed silica sand which was secured to the bottom of the casing with fine nylon gauze. Leaching began on 15 April 1991 and the lysimeters were leached with a constant 1 cm hydraulic head of de-ionised water. The leachate was collected in 0.1 pore volume increments for analysis and the time of leaching recorded. The fractional pore volume is defined as the ratio of the volume of leachate to the total volume of water-filled pores in the lysimeter during leaching. The pore volume of the core was calculated from the bulk density cores taken immediately adjacent to the core, assuming a particle density of 2.65 g. cm<sup>-3</sup>. Leaching continued until an equivalent of 2 pore volumes had been collected or in the case of the very slow cores, a period of 21 days had elapsed since leaching began (first leaching).

Immediately after the first leaching, the equivalent of 10 tonne ha<sup>-1</sup> of gypsum (CaSO<sub>4</sub>) was applied to the surface of all cores. They were leached again with de-ionised water until an equivalent of 2 pore volumes had been collected or a further 8 days had elapsed (second leaching).

To imitate the effect of a wetting and drying cycle, the cores were allowed to dry for 78 days in a glass house. The cores were then rewet from the top with de-ionised water over an 11 day period. The drainage water was allowed to settle at the base of the cores to ensure complete rewetting.

The cores were then leached again with de-ionised water until they maintained a constant saturated hydraulic conductivity ( $K_{sat}$ ) (third leaching).

#### CHEMICAL ANALYSIS

Each aliquot of leachate (0.1 pore volume) was analyzed for chloride with a "Waters" ion exchange chromatograph and "Vydac 3021C" anion exchange column using 3 mM phthalic acid eluent at pH 4.90. The electrical conductivity of each aliquot of leachate was also determined. The pH of bulk soil samples was determined using a 1:2.5 soil to water ratio. The water soluble chloride content and electrical conductivity of the bulk soil samples were also determined using a 1:5 soil to water ratio for extraction (Blakemore *et al.* 1987). The conductivity was converted to percent soluble salt using the equation of Blakemore *et al.* (1987):

$$K_{25}, (\text{mMHO/cm}) \times 0.35 = \% \text{ soluble salt}$$

The soil cation exchange capacity and exchangeable sodium percentage of the bulk soil samples were determined by leaching with 1 M ammonium acetate at pH 7 (Blakemore *et al.* 1987). Bulk soil samples were also analyzed for extractable boron using an azomethine-H method with a hot 0.02 M CaCl<sub>2</sub> extraction (Parker & Gardner 1981). After leaching, the cores were sectioned into depth increments and analyzed for soluble salts, water soluble chloride and hot CaCl<sub>2</sub> extractable boron.

Soil properties were compared to values listed in Blakemore *et al.* (1987) for New Zealand soils.

#### SOIL CLASSIFICATION

The soil in the study area is mapped as a Kaiapoi fine sandy loam, formed from greywacke alluvium (Raeside & Rennie 1974). Typical soil analysis for this non-saline non-sodic soil is pH 6.0, cation exchange capacity of 16.6 meq/100g, and an exchangeable sodium percentage of 1.2, for the top 15 cm of soil (Raeside & Rennie 1974).

## RESULTS

#### NORMAL RIVERBANK SOIL CONDITIONS

The unirrigated soil is slightly acidic, with a medium to low cation exchange capacity (Table 1). It contains a medium amount of soluble salts and is very high in water soluble chloride, exchange-

Table 1. Comparison of soil conditions between the irrigated and unirrigated banks of the Heathcote River (mean values presented).

	Depth (cm)	Irrigated bank (SEM)	Unirrigated bank (SEM)	LSD ( $P=0.05$ )
Bulk density ( $\text{g.cm}^{-3}$ )	0-10	0.99 (0.10)	1.00 (0.15)	0.25
	10-20	1.44 (0.30)	1.22 (0.15)	
pH	0-10	6.69 (0.15)	6.42 (0.33)	0.30
	10-20	6.46 (0.15)	6.13 (0.41)	
Cation exchange	0-10	12.60 (2.78)	13.51 (4.05)	3.21
capacity (meq/100g)	10-20	10.79 (1.55)	9.06 (4.36)	
Soluble salts (%)	0-10	0.070 (0.049)	0.187 (0.162)	0.129
	10-20	0.066 (0.037)	0.193 (0.168)	
Water soluble	0-10	219 (175)	721 (666)	517
chloride (ppm)	10-20	196 (157)	776 (677)	
Exchangeable	0-10	15.6 (6.9)	19.9 (17.3)	13.2
sodium (%)	10-20	18.9 (7.1)	25.7 (16.3)	
Hot $\text{CaCl}_2$ extractable	0-10	2.00 (0.80)	2.23 (1.47)	1.07
boron (ppm)	10-20	1.52 (1.08)	1.47 (0.66)	

able sodium and hot  $\text{CaCl}_2$  extractable boron.

#### EFFECT OF IRRIGATION

Irrigation reduced the soil soluble salt and water soluble chloride content, and increased the soil pH ( $P<0.05$ ,  $P<0.01$  and  $P<0.01$  respectively) (Table 1). Although the bulk density was greater at 10-20 cm on the irrigated bank and the soil exchangeable sodium and hot  $\text{CaCl}_2$  extractable boron content were slightly lower than on the unirrigated bank (Table 1), these differences were not statistically significant due to the considerable variability between individual soil samples.

#### LEACHING EXPERIMENT

Because the saturated hydraulic conductivity ( $K_{\text{sat}}$ ) of the cores shows extreme variability, the data from each core is presented (Fig. 2a & b). Core 6 was not included on Figure 2b but initially had a constant  $K_{\text{sat}}$  of approximately 126 mm/h. After the addition of gypsum the  $K_{\text{sat}}$  of core 6 declined and remained at approximately 30 mm/h. The mean  $K_{\text{sat}}$  over the first two pore volumes (first leaching) were 5 and 29 mm/h for irrigated and unirrigated banks respectively (not significantly different). Generally the  $K_{\text{sat}}$  was either very low or rapidly declined during the first leach-

ing, after the initial wetting phase (Fig. 2a & b). Of the four cores that became impermeable during the first leaching, three were from the irrigated treatment (Fig. 2a). Cores 4 and 6 were exceptional as they had a reasonably constant  $K_{\text{sat}}$  before the addition of gypsum. During the second leaching, after the addition of gypsum, the cores that were still permeable developed a more constant  $K_{\text{sat}}$  (Fig. 2a & b). However the mean  $K_{\text{sat}}$  continued to decline (Table 2). Only 5 cores were still permeable at the conclusion of the second leaching. A large increase in  $K_{\text{sat}}$  occurred during the third leaching after the cores went through a wetting and drying cycle (Table 2).

The electrical conductivity of the leachates was also low or declined rapidly during the first leaching (Fig. 3a & b). The electrical conductivity of the leachate samples was also variable between cores. The mean initial conductivity was 2.1 and 5.1 mMH0/cm for irrigated and unirrigated cores respectively (not significantly different). Applying gypsum produced a rapid increase in leachate electrical conductivity.

The water soluble chloride was rapidly leached from the cores that remained permeable with most of it being removed by the first two pore volumes of leachate (Fig. 4a & b). The amount of

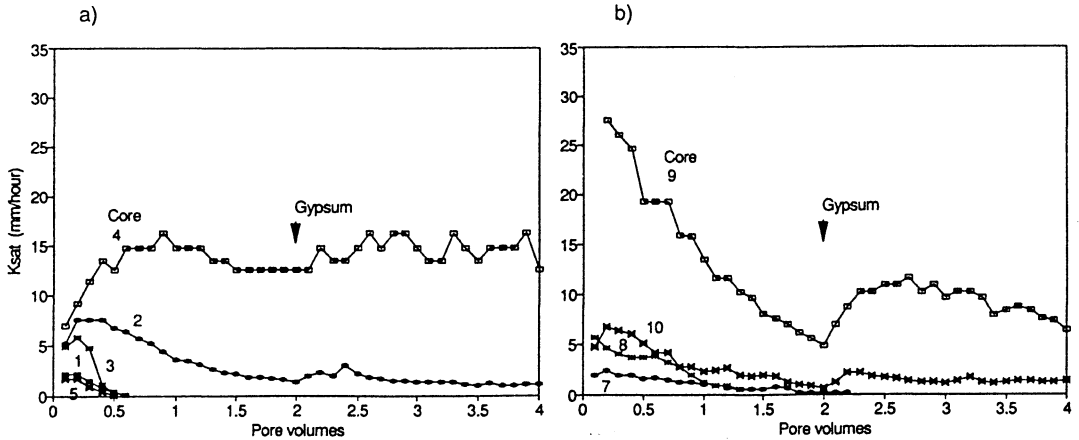


Figure 2. Change in  $K_{sat}$  with leaching and 10 tonne.ha<sup>-1</sup> gypsum addition: (a) Irrigated cores; (b) Unirrigated cores.

Table 2. Change in mean  $K_{sat}$  of the soil cores over three leachings.

	$K_{sat}$ (mm/hour)	(SEM)
First leaching <sup>1</sup>	15	(39)
Second leaching <sup>2</sup>	5	(10)
Third leaching <sup>3</sup>	268	(565)
LSD ( $P=0.05$ )	301	

<sup>1</sup> With de-ionised water.

<sup>2</sup> With de-ionised water after applying 10 tonne/hectare of gypsum.

<sup>3</sup> With de-ionised water after applying 10 tonne/hectare of gypsum and drying and rewetting.

water soluble chloride in the cores was also variable. The mean initial chloride concentrations in the leachate for irrigated and unirrigated cores were 371 and 546 mg/0.1 pore volume respectively (not significantly different).

Leaching with approximately 550 mm (4.3 pore volumes) of water significantly reduced the soluble salt and water soluble chloride content of the soil in the cores (Table 3 in comparison to Table 1) ( $P<0.01$  and  $P<0.001$  respectively). Leaching also reduced the soil hot  $\text{CaCl}_2$  extractable boron content but to a lesser extent ( $P=0.053$ ).

After leaching the effect of irrigation was less apparent (Table 3). There was no significant difference in soluble salt and hot  $\text{CaCl}_2$  extractable

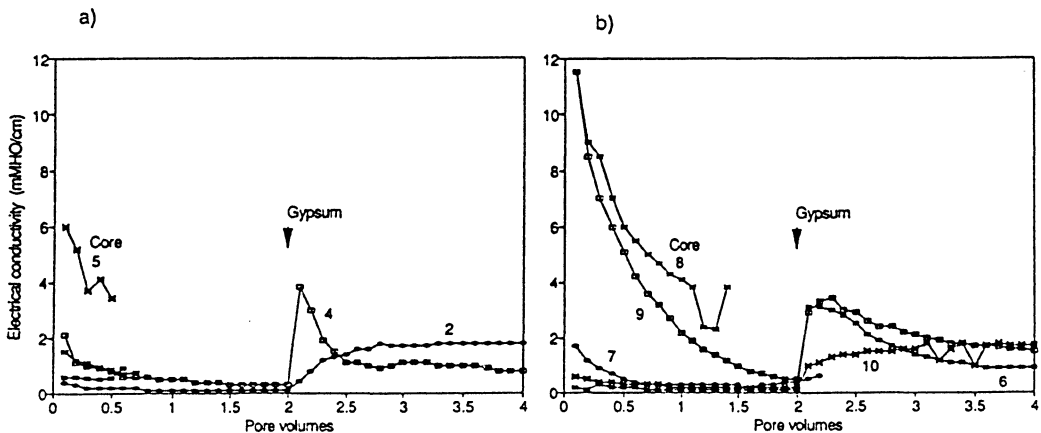


Figure 3. Change in leachate electrical conductivity with leaching and 10 tonne.ha<sup>-1</sup> gypsum addition: (a) Irrigated cores; (b) Unirrigated cores.

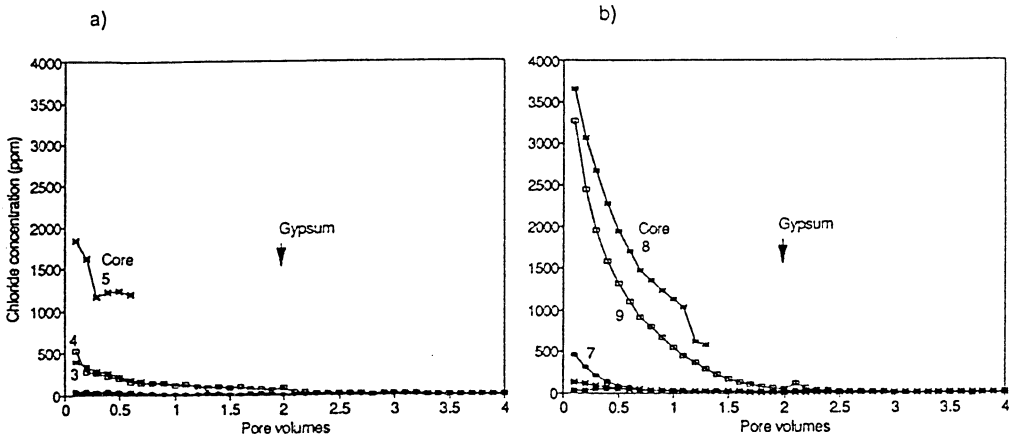


Figure 4. Change in leachate chloride concentration with leaching and 10 tonne.ha<sup>-1</sup> gypsum addition: (a) Irrigated cores; (b) Unirrigated cores.

boron contents, but the leaching of water soluble chloride was more efficient from the unirrigated cores ( $P<0.001$ ).

DISCUSSION

The study site is an important area of interest as previous work has established that it is the upper limit of significant salt water penetration during one neap tidal cycle (Christchurch City Council 1991b). There is a considerable build up of salts in the soil from the translocation and subsequent evapotranspiration of the river water. Plant tolerance to soil salinity varies and also depends on the distribution of salt in the soil and the depth to the water table (Gupta & Abrol 1990). More sensitive species are inhibited by soil salinity

values of 1-4 mMHO.cm<sup>-1</sup> (0.4-1.4% soluble salt) (Gupta & Abrol 1990). Values obtained in this study were only 0.2% soluble salts on the unirrigated bank, but that was after considerable rainfall.

The higher bulk density in the subsoil on the irrigated bank could be due to the dispersion and translocation of clay down the profile. The artesian water that was used to irrigate this bank would have a relatively low electrical conductivity (although not as low as rainfall) facilitating this translocation of clay. The soil surface is particularly susceptible to dispersion as it is exposed to raindrop impact and other physical disturbance (Shainberg *et al.* 1989), which can cause a large reduction in infiltration and increased runoff (Shainberg 1985). For this reason trickle irriga-

Table 3. Soil conditions in the cores after leaching with approximately 550 mm water (4.3 pore volumes).

	Depth (cm)	Irrigated bank (SEM)	Unirrigated bank (SEM)	LSD ( $P=0.05$ )
Soluble salts (%)	0-10	0.072 (0.018)	0.068 (0.018)	0.018
	10-20	0.053 (0.008)	0.053 (0.017)	
Water soluble chloride (ppm)	0-10	42.7 (23.7)	5.9 (2.3)	19.7
	10-20	30.5 (16.3)	5.8 (2.5)	
Hot CaCl <sub>2</sub> extractable boron (ppm)	0-10	1.35 (0.57)	1.49 (0.99)	0.78
	10-20	0.99 (0.47)	1.12 (0.67)	

tion or low energy sprinklers may reduce surface crusting compared to conventional sprinklers (Shainberg *et al.* 1989).

The irrigation programme appeared to be effective in reducing the soluble salt and water soluble chloride contents in the surface soil horizons, but was less effective at removing the exchangeable sodium and hot  $\text{CaCl}_2$  extractable boron. The exchangeable sodium was slower to leach as it was retained on the cation exchange sites in the soil. The use of gypsum facilitated the release and subsequent leaching of sodium as calcium ions replace sodium ions on the cation exchange sites. Gypsum was not used for the Council's irrigation programme during the summer of 1989/90 but is subsequently being used. Boron is known to leach more slowly than NaCl and on average it takes three times more water to remove excess boron than NaCl (United States Salinity Laboratory Staff 1954). This was apparent in the leaching experiment as there was little hot  $\text{CaCl}_2$  extractable boron leached, comparing Tables 1 and 3. After leaching with 550 mm water the soil hot  $\text{CaCl}_2$  extractable boron level was still potentially toxic to some plant species (sensitive species can find values of 1.5 ppm B toxic (Aubert & Pinta 1977)). As most of the boron in soil is adsorbed by organic matter, clay and sesquioxides and very little of it is in solution, it is slow to leach. As adsorption of boron decreases with pH, leaching can be sped up by acidifying the soil (Keren & Bingham 1985). Another strategy to increase boron leaching is to irrigate over dry periods of the year, as this reduces wetting and drying cycles favouring boron adsorption, and increases leaching (Keren & Bingham 1985). Applying gypsum will actually increase boron adsorption both by increasing the pH and by increasing the ionic strength of the soil solution. Both these effects reduce the thickness of the diffuse double layer on the cation exchange sites causing an increase in boron adsorption (Keren & Bingham 1985). Although this will slow the rate of boron leaching, it may also reduce boron toxicity to plants in the short term.

The first leaching illustrated the rapid drop in  $K_{\text{sat}}$  that occurs when leaching a sodic soil with a solution of low electrical conductivity (approximating rainfall). Clay and other colloids are rapidly dispersed clogging pores and reducing the  $K_{\text{sat}}$ .

The addition of gypsum gave an almost immediate increase in leachate electrical conductivity. Gypsum also causes sodium to be replaced by calcium on the exchange sites (Shainberg *et al.* 1989). Both of these processes reduce the thickness of the diffuse double layer causing colloids to flocculate, hence the increased and constant  $K_{\text{sat}}$  of the cores that were still permeable. The impermeable cores only benefited from gypsum addition after a wetting and drying cycle as the leachate of high electrical conductivity could not penetrate the cores. Once dry the soil colloids did not disperse when rewet due to the high electrical conductivity of the leaching solution. All cores had a large increase in  $K_{\text{sat}}$  during the third leaching due to this effect. Work overseas by Sharma & Khosla (1984) and Patcharapreecha *et al.* (1990) has also shown gypsum maintains the  $K_{\text{sat}}$  when leaching saline and sodic soils. Patcharapreecha *et al.* (1990) found that gypsum reduced clay dispersion and maintained the  $K_{\text{sat}}$  for two years following application.

The soils of the area are extremely variable. Some areas have suffered from vehicular compaction and others have been modified by dredging operations and stop bank measures. Although there is considerable variability between samples in this experiment, it appears to be a realistic sample of river bank conditions in the area. The effect of rainfall between samples may also have increased the soil variability as approximately 10% of the annual precipitation occurred between the collection of some samples. As the samples were taken firstly from the irrigated bank, the extra percolation through the unirrigated soils may have reduced the apparent effect of irrigation in this experiment, and the salinity of the unirrigated bank.

In conclusion, the irrigation programme appears to have been effective, but could be improved by irrigating intermittently using trickle irrigation or low impact sprinklers, in conjunction with gypsum. Soil boron contents will need to be monitored. If necessary, boron could be removed more rapidly by applying a soil acidifier such as elemental sulphur, and continuing with the irrigation programme.

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